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Review

Virtual Reality in Preservice Teacher Education: Core Features, Advantages and Effects

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Abstract: This article presents a review of the research into the use of virtual reality (VR) for preservice teacher education. In addition to generating a description of the nature of VR, the analysis of the 24 included studies showed that the use of VR in preservice teacher education can have several benefits for student teachers and their educators, such as practicing professional competence in safe and diverse VR environments, the possibility of monitoring student development with VR, the use of learning environments that would not be accessible, and distance education for student teachers when schools for internships are located too far away from a teacher training institute. Although research into the effects of the use of VR in preservice teacher education is still limited, the results thus far indicate positive effects on student teachers' motivation, self-efficacy, and various classes of teacher skills. We reflect on the challenges with respect to designing VR environments for preservice teacher education and on studying VR effects on teaching quality and student learning outcomes.

Keywords: review study; virtual reality; teacher education; learning outcomes; teaching quality

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1. Introduction

The use of virtual reality (VR) for educational purposes has gained ground in the last two decades, for example, in the medical domain (e.g., to study human anatomy and molecules and to examine patients [1]) and aviation sector (where VR simulations are used to learn how to fly an airplane [2]). VR originated in the gaming industry and refers to a three-dimensional, nonreal environment usually accessed by the user wearing VR glasses and special VR gloves (and in some cases also a microphone), which are connected to a computer system. In education, teachers see the potential of such forms of VR for use in their classrooms, for example, for exploring locations that are otherwise difficult or impossible to visit (outer space, oceans, historical sites from a different era) or for teaching geometry (where students can see shapes in 3D simulations) and biology [3]. However, the use of these forms of VR for classroom teaching is still limited [4]. This applies even more to the use of VR in preservice teacher education [5], although practicing professional skills in virtual environments might be very beneficial for preservice teachers. The focus of this study is on all kinds of preservice teacher education. In preservice teacher education (in contrast to for example K-12 teachers teaching in schools), student teachers learn to teach at the teacher training institute, as well as in internships in schools where they teach and learn under the supervision of an experienced teacher. VR can have several benefits for student teachers and their teachers, such as practicing professional competence in safe and diverse VR environments [6], the possibility of monitoring student teachers' professional development by means of VR, and the use of learning environments that otherwise would not be accessible. Now that a number of empirical studies into VR use in preservice teacher education have become available, this review aims to map this new area in order to create an overview of and gain insight into the core features and effects of VR use in preservice teacher education.

The following research questions are answered:

1. What are the core features of VR use in preservice teacher education, and what advantages does it offer?
2. What effects of VR use in preservice teacher education have been found?

2. Method

2.1. Search: Databases and Key Words (Terms and Databases)

In order to answer our research questions, a systematic review of the literature was conducted [7]. The following databases were searched for relevant articles: EBSCOhost (which includes ERIC, PsycINFO, PsycArticles), Science Direct, Web of Science, JSTOR, Wiley Online Library, Google Scholar, Scopus, and Dissertation Abstracts. As search terms, we used the following keywords: VR/Virtual Reality/Mixed Reality AND Teacher Education/Teacher Training/Teacher Professionalization/Student Teachers, and similar Dutch terms (lerarenopleiding, leraren-in-opleiding, docenten-in-opleiding). These search terms were selected after a first exploration of the literature on VR in preservice teacher education. Articles, book chapters, unpublished doctoral dissertations, and conference proceedings were included in the search.

2.2. Selection of Publications

The search results were filtered for English and Dutch publications between 2000 and 2020, allowing us to include studies from early technological developments and recent publications, which resulted in 6067 publications (see Figure 1). Since the aim of this review was to map the new area of the use of VR in teacher education, we chose a broad period for the review of the literature. By doing so, we also could include the first studies into VR in teacher education and provide an overview from the start of this new development till 2020. As such, this study provides a good starting point for future (review) studies on VR in teacher education. Further selection of publications followed the PRISMA method for identification of studies [8] based on the keywords in the abstracts and the titles of the publications. The first step, based on two exclusion criteria (removal of duplicate publications or titles and/or abstracts that did not match the keywords for our study), resulted in the exclusion of 6003 publications, leaving 64 publications potentially included.

2.3. Additional Exclusion Criteria and Full-Text Screening

Next, the remaining 64 publications were read in full to check for eligibility. In the present study, the focus was on VR in preservice teacher education as a tool used for training student teachers to become teachers in (pre)primary or secondary education. Publications about teacher professional development for other levels of education and other types of education (e.g., health education, astronomy education, dance education) were excluded (exclusion criterion 3). Publications were also excluded when they focused on online or blended learning in preservice teacher education without a VR component (exclusion criterion 4). Only studies and review studies based on empirical research were included; nonscientific publications (i.e., leaflets, or brochures promoting a specific VR application) were excluded (exclusion criterion 5). This resulted in the exclusion of 34 publications, leaving 30 publications. After a second thorough reading of the 30 publications, 6 more publications were excluded, because these publications also did not meet the exclusion criteria. In the end, 24 publications were considered eligible and thus were included in this review study (see Table 1). Throughout the selection process, both authors discussed the decisions to exclude and include manuscripts to ensure the reliability of the exclusion criteria. Manuscripts were only included if both authors agreed that the exclusion criteria were not applicable to a specific manuscript.

3. Data Analysis

The included 24 publications were read in detail. A matrix (Table 1) was constructed to provide a first overview of the main characteristics and results of the included studies: the sample size, the type of study (intervention study or other), the research design and the research instruments used, the effects studied, and the main study results for every publication. Both authors independently read and coded the publications using the categories, after which the results were discussed until a consensus was reached.

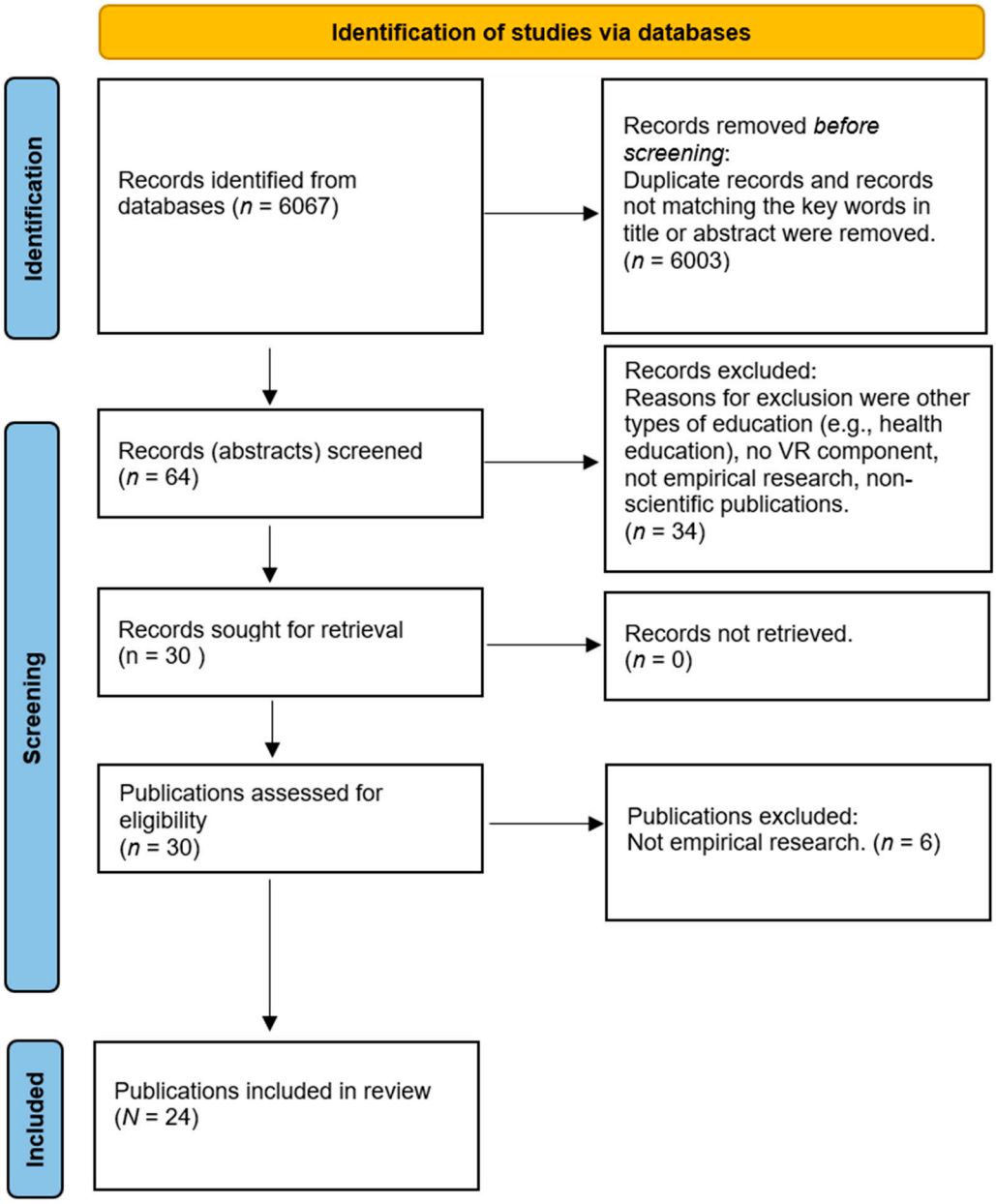


Figure 1. PRISMA flow diagram for selection of studies [8].

4. Results

In this section, the two research questions of this article (RQ 1. What are the core features of VR use in preservice teacher education, and what advantages does it offer? and RQ 2. What effects of VR use in preservice teacher education have been found in the research?) are addressed.

First, a general characterization of the included studies is provided. Most of the 24 studies included in our review were of an exploratory, small-scale nature (15 case studies); five studies had a quasi-experimental research design, one study had an experimental research design, and three were review studies (mostly case studies). Very few of the reviewed studies thus had a research design allowing for strong causal claims (RQ 2: effects of VR interventions). Moreover, the research instruments used in the studies were mostly researcher-made instruments (in 17 studies), and data were often based on self-report. Slavin [9] pointed to the fact that the use of researcher-made instruments results in intervention effects three to four times higher than independent instruments. Self-report also is generally recognized as a source of bias. The research instruments had been validated in (other) research in just four studies, and three studies were review studies. The number of participants in the included studies (apart from the three review studies) ranged from 4 to 311, with 10 primary studies including fewer than 50 participants and 10 primary studies including 50 or more participants. In one study, the number of participants was not reported. The three review studies included research with 4 to 151 participants (See Table 1). The studies included in the three review studies were not included as separate studies in the present study, since they did not meet the inclusion criteria.

5. The Core Features of VR

Not all included studies provide a clear definition of VR and seem to assume that readers know what is meant by VR in teacher education, or that a broad description of VR is sufficient. Fortunately, some studies explicitly define VR. Based on these studies, we defined VR in teacher education, following Billingsley et al. (2019): "A virtual reality environment is a digital, three-dimensional, environment in which users (participants) can be fully immersed and can navigate, manipulate objects, and interact with the environment, and with other participants and objects" (p. 68) [10]. Technically, VR includes a computer capable of generating interactive 3D visualization, a head-mounted display, and trackers that sense the position and orientation of the user [10]). Users can navigate by moving their body parts and interact with objects by physically reaching toward them and pretending to pick them up with their hands [11,12]. Figure 2 provides an example of the use of VR equipment.



A user wearing VR glasses and holding VR controllers in front of a PC screen showing the VR environment. The user wearing the VR glasses sees the environment through the glasses; the screen shows what happens in the environment (Sveinbjornsdottir et al., 2019).

Figure 2. An example of VR use [12].

One of the included papers in this study, by Stavroulia and Lanitis [13], is one of the few studies that provides a clear description of what can be regarded as the three core features of virtual reality. Since their description matches our definition and also matches the broad description of VR in the other studies, we use the characterization of Stavroulia and Lanitis to describe the core features of virtual reality. We combine their description with examples from other studies, underlining their similar approach to virtual reality. Stavroulia and Lanitis [13] characterized virtual reality by three core features: imagination, interaction, and immersion. *Imagination* refers to the possibility for VR users to be in an

imaginary, nonexistent environment that resembles reality. The nonreal environments that were found in the publications included in this review were all imaginable situations in real life and involved VR use in preservice teacher education in all types of educational settings, including a traditional classroom with students sitting in rows of two next to each other [10,14] or a classroom with students from homogeneous or diverse backgrounds (in terms of ethnicity, nationality, socioeconomic background, gender, IQ, learning ability, etc. [11,15–17]. In these settings, student teachers practiced their classroom management skills or their skills for differentiating instruction between students, for example [10,18].

VR environments used in preservice teacher education addressed generic educational qualities such as self-efficacy, classroom management, instructional strategies [14,19,20], or subject-specific aspects [21,22]. An example of a subject-specific VR environment was a VR chemistry lab environment for student teachers to practice their practicum lessons [21]. Other subject-specific examples of VR environments were visiting historical settings, museums, or other countries [11,19]. Other forms of VR use we found were not so much related to classroom teaching but to other aspects of a teacher's job, for instance, VR meetings between a parent and a teacher [19] or collaboratively developing curriculum with other teachers [15]. Figure 3 shows that a VR environment offers users the possibility of experiencing a situation from multiple perspectives, for instance, from the student's perspective as well as from the teacher's perspective. In this way, teachers can develop more understanding of how specific situations are experienced by students [6].



Figure 3. Example of the teacher's (left-hand side) and the student's (right-hand side) perspective in a VR classroom environment [6].

The second VR core feature, *interaction*, refers to the possibility that the VR user and the virtual participants in the VR environment can react to each other's actions [5,17]). For instance, in a VR classroom environment in which the students were entering the classroom after a break, the VR user (the student teacher) has the role of the teacher and he or she has to learn to interact with the students [6]. The virtual students in a VR environment were programmed to react to the student teacher in a specific way, depending on the behavior of the student teacher. Virtual students can be programmed to follow the instructions from the student teacher in the VR environment immediately, but they can also show disruptive behavior towards the student teacher or a fellow student [23,24].

Immersion, the last core feature of VR, means that users can feel fully "immersed" in or "absorbed" by the VR environment [11,12,16] so that "VR allows the users to feel like they are being there" (p. 158) [6]. Users experience deep engagement that overrides their awareness of time, space, and reality. While in the VR environment, users see, hear, and feel hardly anything from the real world. They are completely present in the VR environment, in which they can move themselves and objects and see (from whatever angle they take) and interact with virtual "people" in the VR environment and other users present in the VR environment [5,11,25].

6. The Advantages of VR Use in Preservice Teacher Education

Based on our review of the VR literature, we found that the use of VR for teacher training can have several advantages for teacher educators and student teachers. The first advantage that is mentioned in the literature is the possibility of using VR environments to practice and develop student teachers' professional skills (e.g., [6,10,19,24]) and to develop student teachers' awareness and reflection, for example, with regard to the differences between the students they teach [6,16,26]. For student teachers, practicing professional skills in real-life settings is stressful and raises feelings of uncertainty and low self-efficacy [6,11,20,25]. An advantage of training professional skills in VR is that VR offers a safe environment in which they can practice professional skills as much as they want before they make the transition to the classroom [10]. Moreover, the direct change in settings, from teaching in VR to the reflection outside VR on the experiences in that situation, is very practical and facilitates frequent, direct reflection upon what was experienced. In school internships, one cannot stop every 10 min to reflect on specific teaching experiences. VR also provides a safe space to talk about student teachers' strengths and flaws [6,10,11]. Studies showed that student teachers became more aware of their students' varying individual needs in the classroom (for instance, as a result of the fact that student teachers could "talk" with different students in the VR environment and ask them about their needs [6].

Another VR advantage is that teacher educators can monitor student teachers' development by means of VR monitoring software [5]. A study by Stavroulia and Lanitis [5] showed how VR software can collect all sorts of data about various variables related to the behavior of student teachers in the classroom and their interactions with students (movements, speech, interactions). This information was valuable for teacher educators in their decisions regarding the further professional development of student teachers.

VR environments can also replace expensive parts of the traditional learning environment. For instance, instead of building and maintaining STEM laboratories, student teachers can practice subject-specific pedagogical skills within VR environments that are cheaper and can be kept up to date more easily [21,22]. VR also provides teacher training institutes with the opportunity to let student teachers work in more diverse learning environments (presented as VR environments) and to "visit" places in VR that are less accessible or not at all accessible in real life [11]. For example, VR environments were created with diverse classrooms (in terms of ethnicity, nationality, socioeconomic background, gender, IQ, etc.) or classrooms with special needs students [5,12,25,26]. In such environments, the student teacher can have a dialogue with a student, walk towards a student who is showing off-task behavior, or correct student behavior and experience the effects.

Finally, VR offers possibilities for distance learning; for instance, sometimes preservice teacher education institutes or schools for internships are far away (e.g., in rural areas in Australia [11]. In these situations, VR can replace (parts of) the traditional learning environment (e.g., roleplay, workshops, internships, lectures [16,19,20]. In this way, teacher training institutes can enroll students, including students who live in rural areas and who otherwise would not be able to participate in face-to-face educational activities at preservice teacher education institutes [11,15,16].

7. What Effects of VR Use Have Been Found in Preservice Teacher Education?

The effects of VR use that we found in the studies that we analyzed are presented in Table 1.

Table 1. The features of the included studies and their main findings by type of VR effect studied.

VR Effects Studied	Author(s)	Research Design	Intervention or Other Study	Research Instruments Used	N [1]	Main Findings
Motivation to teach using VR	Bujdoso, 2017	Case study	Participants practicing in a VR environment in various situations	Group discussion	41	Practicing in a VR environment was found to increase the motivation to use VR more often.
	Cooper et al., 2019	Case study	Descriptive study of participants' perceptions of the value of using VR	Questionnaire	41	Almost all of the participants indicated that they were willing to use VR in their classes.
	Jacka, 2015	Case study	Participating in a workshop on a VR environment	Participants' blog posts	311	More than half (52%) of the participants wanted to use VR in teaching, but perceived barriers. Eighteen percent did not perceive any benefits of VR at all and 30% were "neutral".
	Kim and Blanken-ship, 2013	Case study	A collaborative VR environment for language learning	Participants' reflections	84	The VR environment was evaluated as "motivating" and "good for out-of-school use".
	Lee and Shea, 2020	Pre/post within-subjects design	Reading articles about VR, experimenting in a VR environment, using VR in the classroom	Questionnaires	38	Participants had a positive attitude towards VR and were more ready to teach after the intervention.
	McPherson et al., 2011	Quasi-experimental	Training in VR classroom environment vs. online training	Questionnaire	151	Students were more motivated to use VR in their schools as compared with students who received an online tutorial.
	Pavlin and Suznjevic, 2019	Case study	Descriptive study of student teachers' attitudes towards the use of VR	Questionnaire	83	Even though a majority of students had positive expectations for the use of VR, only a few of them felt competent enough to use it in the classroom.
	Ripka et al., 2020	Case study	Descriptive study of the motivation to use VR	Interviews	12 student teachers 10 teacher educators	VR can enrich classes through interactive engagement. Flexibility and "tailor-made customization" are vital factors. There were worries about ethics and data usage.
	Zaretsky, 2011	Case study	Training in VR (physical education) vs. online training	Questionnaire, log data	6	Student teachers' motivation and skills to use VR for their teaching increased during the training in a VR environment.

Table 1. *Cont.*

VR Effects Studied	Author(s)	Research Design	Intervention or Other Study	Research Instruments Used	N [1]	Main Findings
	Billingsley and Scheuer-mann, 2014	Review of 6 case studies and 1 quasi-experimental study	-	Questionnaires, interviews	2–151 (7 studies)	VR technology was found to improve student teachers' self-efficacy for teaching students with special education needs.
	Cooper et al., 2019	Case study	Descriptive study of participants' perceptions of the value of using VR	Questionnaire	41	Participants had low self-efficacy for using VR in their teaching.
Self-efficacy for teaching	Dalinger et al., 2020	Case study	Descriptive study into experiences in a VR classroom environment	Interview	13	Increased confidence in applying general teaching skills was perceived.
	Lee and Shea, 2020	Case study	Reading articles about VR, experimenting in a VR environment, using VR in the classroom	Questionnaires	38	Teacher self-efficacy increased after the intervention.
	McPherson et al., 2011	Quasi-experimental	Training in VR classroom environment vs. online training	Questionnaire	151	Instructional self-efficacy of participants who received the VR training was higher compared with participants who watched an online tutorial.
	Sveinbjorns dottir et al., 2019	Case study	Training in a VR environment about teaching students with autism	Classroom observation instrument	4	The quality of Instruction while teaching students with autism improved as a result of VR training.
	Theelen et al., 2019	Review of 10 case studies and 5 quasi-experimental studies		Questionnaires, interviews	4–149 (15 studies)	Four studies showed positive effects of VR simulations on student teachers' self-efficacy.
Classroom management skills	Billingsley et al., 2019	Review of 2 case studies and 5 quasi-experimental studies		Questionnaires, student reflections	4–90 (7 studies)	VR can be helpful for improving classroom management skills.
	Bower et al., 2020	Case study	Workshop on the use and benefits of VR	Questionnaire, interviews	65	Performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, habit and behavioral intention influenced the (intentional) use of VR.
	Dieker et al., 2015	Case study	Teacher educators use of a VR program "Teach Live"	VR software analysis	10,000	VR is used in classroom management and instructional strategies (among others)

Table 1. *Cont.*

VR Effects Studied	Author(s)	Research Design	Intervention or Other Study	Research Instruments Used	N [1]	Main Findings
	Kim et al., 2017	Quasi-experimental	Three groups worked with three different VR environments on classroom management	Electro-cardiogram	84	Student teachers' ECGs showed that they "perceived" a smaller psychological distance in a classroom management VR environment when they were closer to other persons in the VR.
	Mouw et al., 2020	Case study	Descriptive study of experiences of student teachers and teacher educators with a VR environment on classroom management skills and teacher resilience	Interviews	4 student teachers 6 teacher educators	VR for training classroom management skills and promoting teacher resilience was experienced positively by student teachers and teacher educators.
	Stavroulia et al., 2019	Case study	VR environment about incidents in school	Heart rate data and questionnaire	25	VR was found to be useful by student teachers for learning how to react to incidents in school.
	Stavroulia and Lanitis, 2017	Case study	VR environment in which student teachers could take different roles (i.e., teacher, student, etc.).	Questionnaire	Not reported	VR was found to be useful for acquiring classroom management skills (especially for dealing with bullying students).
	Theelen et al., 2019	Review of 10 case studies and 5 quasi-experimental studies		Questionnaires, interviews	4–149 (15 studies)	VR was found to be helpful for improving classroom management skills.
	Billingsley et al., 2019	Review of 2 case studies and 5 quasi-experimental studies		Questionnaires, student reflections	4–90 (7 studies)	Student teachers' knowledge of a particular student disability increased.
	McPherson et al., 2011	Quasi-experimental	Training in VR vs. online training	Questionnaire	151	Students after the VR intervention experienced significantly better skills for teaching students with special education needs as compared with students who received online training.
	Passig, 2011	Quasi-experimental	Training in a VR environment vs. watching an instructional video	Questionnaire, interview	80	Participants in the VR environment scored significantly higher on recognizing the needs of students with special education needs compared with the control group who watched an instructional video.

Table 1. *Cont.*

VR Effects Studied	Author(s)	Research Design	Intervention or Other Study	Research Instruments Used	N [1]	Main Findings
Knowledge/pedagogical skills special needs education	Stavroulia and Lanitis, 2019	Quasi-experimental	Training empathy and reflection skills in a VR environment vs. a real classroom	Questionnaire	33	Participants in a special education needs VR environment scored higher on self-reflection skills regarding special education student needs as compared with the control group.
	Artun et al., 2020	Quasi-experimental study	Training in a VR environment (STEM laboratory) vs. real-life training	Skill test and interviews	54	The experimental group scored better on the subdimension "experimenting" compared with the control group.
	Lamb et al., 2020	Experimental study	Training in a VR environment (STEM laboratory) vs. real-life training	Questionnaire, eye-tracking data, heart rate	54	No differences between experimental and control group for STEM skills.

[1] Unless otherwise indicated, the number of participants refers to the number of student teachers participating in a study.

Using Desimone's [27] theory of action for teacher professional development (see Figure 4) as a framework for categorizing the results of the empirical studies of the effects of VR use, the studies included in our review focused mainly on effects on teacher knowledge, skills, and attitudes towards VR (see Table 1). Desimone's theory of action regarding the effects of teacher professional development interventions (in our case VR interventions) includes four components (Figure 4). First, teachers participate in a VR intervention meant to improve their professional competence. This ideally results in improved teacher knowledge, and/or teacher skills, and/or teacher attitudes (block 2). Hopefully, the teachers apply what they have learned in the classroom (block 3) and that way improve their teaching quality, which may lead to improved student learning (the last block).

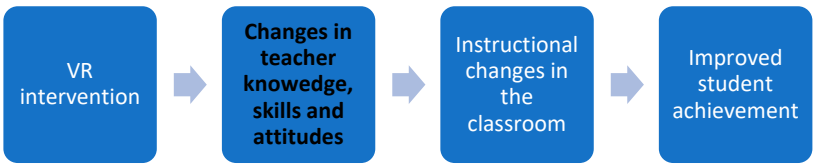


Figure 4. Desimone's theory of action for teacher professional development (*adapted from Desimone, 2009*) [27].

There was very little empirical evidence for the improvement of classroom teaching, let alone for improved student achievement as a result of the use of VR in preservice teacher education. The studies included in this article reported some indications of positive effects of the use of VR in preservice teacher education on these outcomes for student teachers:

(1) Motivation to use VR for teaching (nine studies);
(2) Self-efficacy regarding teaching in general (seven studies);
(3) Classroom management skills (eight studies);
(4) Knowledge and skills for teaching students with special needs (four studies);
(5) STEM/science-related skills (two studies).

Some studies reported multiple effects, for instance, effects on the motivation to use VR for improving teacher skills and effects on the knowledge and pedagogical skills required for teaching special-needs students.

Student teachers in general proved to be motivated to use VR for teaching after being introduced to its opportunities and possible effects. However, not all student teachers immediately felt competent to do so. Teachers' self-efficacy refers to teachers' beliefs in their own professional capacity and ability to influence student learning [28]. They are more likely to implement new practices, such as VR, when they have a high sense of self-efficacy [29]. Seven of the studies on VR showed that using VR supported student teachers' self-efficacy (e.g., [12,14]) which is an important finding. More specifically, the improved self-efficacy of student teachers after training in a VR environment was found to be related to general instruction skills, classroom management [14,20,24], and teaching a specific group of students (e.g., students with special needs [12,14,25]). With regard to improved self-efficacy concerning classroom management, Theelen et al. [24] reported that contributing factors were the available resources, the degree of realism of the VR environment, and whether teachers received feedback on their learning process or not. With respect to using VR for learning to teach students with special educational needs and dyslexia, McPherson et al. [20] found that student teachers who worked in a VR environment to learn to teach more inclusively and to teach students with special educational needs scored higher on instructional self-efficacy and on general teaching skills compared with the control group teachers who did not work with VR. A similar result was found by Passig [26], who compared student teachers who participated in a VR environment (the experimental group) with students who watched an instructional video on teaching dyslexic students (the control group). Both the scores for lesson observations and self-reports from student teachers' regarding their ability to observe and recognize dyslexic students were significantly higher for the experimental group. As can be seen in Table 1, being in a VR environment also proved to significantly improve student teachers' levels of reflection and their awareness of their own emotions and of the emotions of their students in the classroom [6].

The studies of teachers' skills for STEM reported on the effects on student teachers of using STEM lab environments that were either in VR or in real life [21,22]. Both Lamb and Etopio [22] and Artun and colleagues [21] found no statistically significant differences between the experimental group of teachers (practicing STEM skills in a VR environment) and the control group (real-life training) with respect to their eye movements, heart rate [22], and lab skills [21]. According to Lamb and Etopio [21], the physiological data provide information about the level or the "depth" of immersion in a VR environment (and "truly" feeling that you are in this environment).

8. Conclusion, Discussion, and Future Directions

The goal of this study was to describe the characteristics of virtual reality as used in preservice teacher education and the benefits VR offers for preservice teacher education, as well as to map its effects as found in empirical research. We found that a lot is still unknown about the effective use of VR in preservice teacher education. Our analysis did show that, in VR environments, student teachers develop (part of) the professional attitudes, knowledge, and skills they need for their teaching job without participating in internships. We saw advantages of VR use, such as practicing aspects of teaching before student teachers go to real classrooms [10,23,30], the monitoring of student teachers' progress as a basis for instructional differentiation by teacher educators [18], working in diverse environments that otherwise would be impossible for student teachers (e.g., schools in other countries/parts of the country, schools with different kinds of students, e.g., special needs students [11,15–17], and developing awareness of the differences between students. VR has been used as an additional tool or has replaced part of the offline learning environments; however, the forms of VR that have been developed so far are still applications that are quite limited with respect to the forms of support they offer [4].

The research in this field so far can be characterized as exploratory, small-scale research, using methods that lead to results that should be used with caution and need to be tested in larger studies with research designs that allow more causal claims. Researchers have focused on effects such as student teachers' motivation to use VR, their self-efficacy,

classroom management skills, and competence to teach students with special needs and to teach STEM/science. The effects reported give the impression that VR could have a positive impact on various important aspects of the required competencies of student teachers. In future research, we must test these findings with rigor, as well as study the effects of VR use on the quality of classroom teaching and student learning [27], about which we do not yet have evidence.

9. Challenges of the Use of and Research into VR for Preservice Teacher Education

Our study shows that the investigation of VR use and its effects is still in its pioneering phase but that VR use seems to have potential benefits for preservice teacher education. The exploratory nature of the research in this field is not surprising, as it is a new field of design and study, and we are lacking the resources for large-scale evaluations of VR implementations. An important reason for this is probably the costs involved in designing, implementing, and studying VR applications. A challenge therefore first of all relates to the financial resources needed for the design of VR environments, for example, developing scenarios, and storyboards and preparing actors for simulations [10]. We will probably need governmental organizations, alone or in combination with interested companies, to provide the resources to design and study high-quality VR environments more rigorously. An important aspect that needs to be addressed in future research on VR effects is the study of the mechanisms that cause effects. We need to know not only whether the desired effects are accomplished but also via what mechanisms these effects occur.

10. Deliberate Design and Evaluation

In order to achieve the potential of VR, we will need to deliberately design and test VR applications for preservice teacher education and ask ourselves what student teacher competencies we especially want to affect with VR: improving student teachers' attitudes, knowledge, specific teaching skills, or complex, integrated combinations of teacher attitudes, knowledge, and skills. If the answers to these questions are known, we should deliberately think about what VR content (*what* is to be learned by student teachers) and VR methods (*how* that content is to be learned) may accomplish these learning goals. If we make such decisions deliberately, we can document the characteristics that we design more explicitly and in detail in our publications (so far, this is not often the case yet), and we can study the effects of *specific kinds of realizations* of VR. It is important to be aware that when we study 'THE' effects of VR use, we are always studying the effects of specific VR designs. VR can take many forms, and different designs may lead to different effects, so the design decisions made will be important for the effects found. Along this road, we may be able to identify the VR design characteristics that influence the effectiveness of VR environments for specific student teacher learning goals. The same applies to the contexts in which VR designs are implemented. Some VR designs may be more effective in some contexts (e.g., depending on the features of the participating student teachers and students) than in others. Moreover, if we want to expand our knowledge of the effects of VR interventions for all of Desimone's [27] categories in Figure 3, then we need experimental studies in which student teachers are randomly assigned to the experimental or control group (business as usual) and in which standardized instruments are used for studying student teacher growth with respect to their knowledge, attitudes, and professional skills, the use of those competencies in the classroom. and the impact thereof on student outcomes. Ideally, such studies will be conducted on a large scale and with an adequate timespan to avoid short-term "enthusiasm effects" that are not representative of long-term impacts. The possibilities of the use of VR for improving student teacher training and possible student outcomes are promising and worth future research in order to improve teacher education.

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